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ORIGINAL ARTICLE

Variation of rainfall features across the Plain of Reeds under the impacts of climate change[1]

Variação das características pluviométricas na Planície de Reeds sob os impactos das mudanças climáticas

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HIGHLIGHTS:

The Plain of Reeds befallen a slight change tends in annual rainfall and rainy season rainfall.
An increasing trend in dry season rainfall is a living proof of the impact of climate change on rainfall factors.
An increase in the dry season rainfall is expected as a positive highlight for the agricultural sector.

ABSTRACT: Globally, there is enough evidence to affirm that climate change is one of the main factors causing the changing trends in rainfall features (CTRFs). The aim of this study, therefore, is to assess the CTRFs across the rice cultivation regions (RCRs) of the Plain of Reeds in Vietnam. Vietnam is a prime example of the impacts of climate change (ICC) on agricultural activities. Daily rainfall data series from 16 observation stations during the period 1984-2015 were appraised for quality and then the CTRFs were detected by applying the Mann_Kendall test and Sen's slope estimator. The quality of rainfall data at all observation stations is homogeneous with a significance level of 0.05. Over a year, the trends in rainfall features slightly increased at most obsrvation stations, except for Hong Ngu and Moc Hoa. Additionally, the trends in rainfall features slightly decreased in rainny season rainfall (RSR) at 10 out of 16 observation stations, while insignificant to significant increasesing in dry season rainfall (DSR) were detected at all observation stations.

Key words: agriculture, Mann-Kendall test, Pettitt, rainfall decline, rice

RESUMO: Globalmente, há evidências suficientes para afirmar que a mudança climática é um dos principais fatores que causam as tendências de mudança nas características das chuvas (TMCCs). O objetivo do estudo, portanto, é avaliar as TMCCs nas regiões de cultivo de arroz (RCAs) da Planície de Reeds. Vietnã é um excelente exemplo dos impactos das mudanças climáticas (IMC) nas atividades agrícolas. Para realização deste estudo, as séries diárias de dados de precipitação em 16 estações de observação durante o período de 1984-2015 foram avaliadas quanto à qualidade e, em seguida, foram detectadas as TMCCs aplicando o teste de Mann-Kendall e o estimador de inclinação de Sen. A qualidade dos dados pluviométricos em todas as estações de observação é homogênea com nível de significância de 0,05. Na escala anual, houve uma tendência crescente insignificante na maioria das estações de observação, exceto Hong Ngu e Moc Hoa, e uma tendência insignificante decrescente na precipitação da estação chuvosa foi detectada em 10 das 16 estações de observação, enquanto tendências crescentes insignificantes a significativas foram detectadas em todas estações de observação. Pode-se confirmar que a área de estudo está passando por um estágio crescente da precipitação na estação seca (PES). Os achados do estudo contribuem positivamente para as atividades agropecuárias, ampliando o entendimento do IMC sobre as características pluviométricas.

Palavras-chave: agricultura, teste de Mann-Kendall, Pettitt, declínio de chuva, arroz

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Introduction

In recent decades, climate change has strongly affected aspects of life, with its consequences thought to be a major theme of humanity in the 21st century (Bartels et al., 2020; Dang et al., 2021). According to Alhathlou (2021), intensifying human activities have caused serious effects on the global water cycle, and extreme weather events (EWEs) are an inevitable consequence of climate change. The EWEs are, therefore, seen as a major factor contributing to the loss of crops (Lee & Dang, 2019; AlSubih et al., 2021). Relevant studies have pointed out that the frequency of EWEs is increasing as a part of the impacts of climate change (ICC) (Dang et al., 2021; Dinh & Dang, 2022). Rainfall is considered a meteorological factor that closely relates to many aspects of life and where rainfed is considered as the main source of irrigation water provided (Nikumbh et al., 2019; Balcha et al., 2022).

The changing trends in rainfall features (CTRFs) can influence many aspects of life, especially in the agricultural sector (Bartels et al., 2020; Dang et al., 2021). Accordingly, an increase in the rainy season rainfall (RSR) may introduce potential risks, such as seed rot or rice falling near harvest time, leading to a grain yield decline or even a yield loss. A decreasing trend in the dry season rainfall (DSR) can be strongly linked to meteorological drought and saltwater intrusion (Balcha et al., 2022; Lee & Dang, 2019).

Globally, numerous studies related to the CTRFs under the ICC have attracted the attention of the scientific community (Lee & Dang, 2020; Dinh & Dang, 2022). Nowadays, studies on the CTRFs have been commonly deployed at large cultivation regions, such as the conterminous United States by Gershunov et al. (2019) and Risser et al. (2023); in India by Gupta et al. (2021) and Praveen et al. (2020); in Pakistan by Iqbal et al. (2019); in Iran by Ahmadi et al. (2018), and in Saudi Arabia by Alhathloul et al. (2021).

Thus, a study was conducted to assess the CTRFs across the rice cultivation regions (RCRs) of the Plain of Reeds, in Vietnam, applying the Mann_Kendall test and Sen's slope estimator based on collected rainfall data series from 16 observation stations, during the period 1984-2015.

Material and Methods

The Plain of Reeds is located in the northwest region of the Mekong Delta (10° 04' 56" to 11° 00' N latitude and 105° 03' 15" to 106° 09' 33" E longitude), stretching a part of the border of three provinces of Long An, Tien Giang, and Dong Thap with a total agricultural land area of approximately of 700,000 hectares and an average annual yield of rice up to 560,000 tons (Lee & Dang, 2020; Dang, 2021). The area has an altitude varying from 0.5 to 2.0 m above mean sea level (Figure 1). However, the area is currently facing a lack of irrigation water due to the CTRFs, as a part of the ICC (Lee & Dang, 2019; Dang et al., 2021).

Unlike the northern plains of Vietnam, which are controlled by four distinct seasons of the year according to the climatology features, the Plain of Reeds is dominated by the two major circulations in the Northeast and Southwest monsoons, creating the dry season from October to April and the rainy season from May to November (Dang, 2021). Annually, the area receives an average rainfall of approximately 1,465 mm, out of which 85% of rainfall comes from rainy season months (Figure 2).

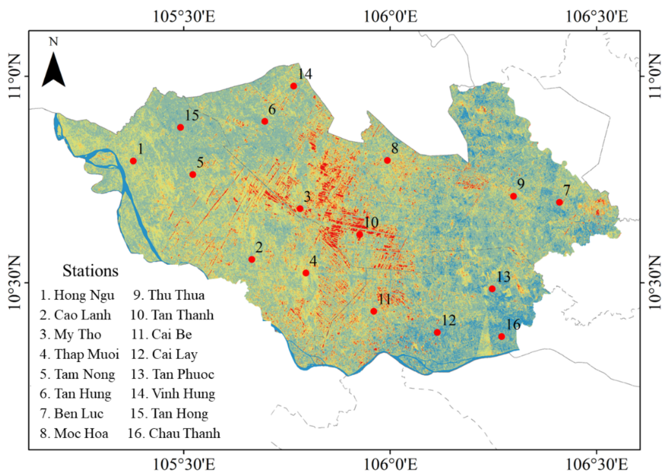

Figure 1. Map of the Plain of Reeds with rainfall observation stations marked red circles

To conduct this research, daily rainfall data series from 16 observation stations across the Plain of Reeds (Figure 1) were collected from the National Centre for Hydrometeorological Forecasting (NCHMF) between the dates 1984-2015. Accordingly, the quality of the rainfall data series was appraised by applying the homogeneity tests, namely the Standard Normal Homogeneity Test (SNHT) and Pettitt tests, based on XLSTAT software. This was then synthesized to total rainfall at seasonal and annual scales for further trend analysis.

To avoid interruption of data series, the present study applied the SNHT to expertise observed rainfall series across the study area (Patakamuri et al., 2020; Praveen et al., 2020). This approach has been applied extensively to detect the discontinuity points in observed data series (Salehi et al., 2020; Lee & Dang, 2020). The SNHT is defined using Eq. 1:

$$Z_i = \frac{\left(Q_i - \bar{Q}\right)}{\sigma_Q} \quad (1)$$

where:

Q_i - is the value of rainfall data series at time step i;
$\bar{Q}$ - is the mean value of rainfall data series; and,
σ_Q - is the standard deviation of rainfall data series at time step i.

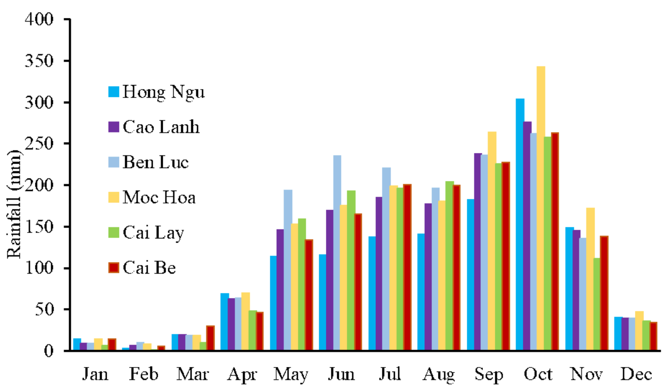

Figure 2. Illustration of monthly rainfall across the study area in the period 1984 - 2015

Assuming the Z_i is a normal distribution, N, the null hypothesis for all variants of the SNHT is H_o with $Z_i \in N(0, 1)$ $i \in \{1, …, n\}$ i.e., the whole series is homogeneous.

When all values in the normalised series are normally distributed with a mean value equal to 0 and standard deviation equal to 1.

Pettitt's test was developed to detect the interruption points in continuous data series (Lee & Dang, 2020; Dinh & Dang, 2022). Accordingly, the Pettitt test requires the data to be input independently, identically distributed random quantities, with the alternative being a stepwise shift in the mean, which is presented (Lee & Dang, 2019; Dinh & Dang, 2022). However, it cannot detect the change points in the distribution series if there is no change in the position of the applied points. Pettitt's test is presented as follows:

By assuming the data series (X) are ranked from 1 to N, when the value of $V_{i,N}$ is defined by Eq. 2:

$$V_i = N + 1 - 2R_i \text{ with } I = 1, 2, 3..., N \tag{2}$$

where R_i is the rank of X_i in the sample of N obtained data series.

And U_i is calculated by Eq. 3:

$$U_i = U_{i-1} + V_i \tag{3}$$

By assuming $U_1 = V_1$ and K_N is calculated based on Eq. 4:

$$K_N = \max_{1 \le i \le N} |U_i| \tag{4}$$

Finally, the Pettitt test is established by Eq. 5:

$$P_{OA} = 2e^{\left\{-\frac{6K_N^2}{N^3 + N^2}\right\}} \tag{5}$$

If the value of P_{OA} is less than a critical value, the test is called the statistical significance when the H_0 is rejected (Dang et al., 2021; Dinh & Dang, 2022).

To conduct this research, a non-parametric statistical method, namely the Mann-Kendall is applied to detect the CTRFs across the study area during the period 1984-2015. Accordingly, the Mann-Kendall test assumes the H_0 of no trend is recorded while a monotonic trend (e.g., increasing or decreasing) is defined as the alternative hypothesis (H_1) (Lee & Dang, 2019; Nguyen et al., 2022). The Mann-Kendall test is defined based on Eq. 6:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sgn}(X_j - X_i) \tag{6}$$

Where $\text{sgn}(X_j - X_i)$ in Eq. 6 is defined by Eq. 7:

$$\text{sgn}(X_j - X_i) = \begin{cases} +1 \text{ if } x_j - x_i > 0 \\ 0 \text{ if } x_j - x_i = 0 \\ -1 \text{ if } x_j - x_i < 0 \end{cases} \tag{7}$$

In a time series, X_i, i = 1, 2, 3, ….., n, the value of S is assumed to be a normal distribution with a mean 0 while the discrepancy of statistics S has calculated applying Eq. 8:

$$\text{var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{j=1}^{m} t_j(t_j - 1)(2t_j + 5)\right] \tag{8}$$

The standard test (Zs) is used to define whether the time series information is a significant trend or not. When the Zs value is defined by applying Eq. 9:

$$Zs = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S-1}{\sqrt{\text{Var}(S)}} \text{ if } S < 0 \end{cases} \tag{9}$$

Accordingly, the positive and negative values of Zs in a normalized test statistic reflect the increasing and decreasing trend, respectively, while the Zs having 0 values reflects a normally distributed data series (Banerjee et al., 2020).

Sen's slope estimator is also known as a non-parametric statistical test which is commonly used to define the true slope of an existing trend. In order hand, it was often used to define the magnitude of change trends in the observed data series (Dinh & Dang, 2022; Nguyen et al., 2022). The Sen's slope is obtained using Eq. 10:

$$\beta = \text{Median}\left(\frac{X_i - X_j}{i - j}\right) \text{ with } j < i \tag{10}$$

where X_i and X_j are input data at time intervals t_i and t_j, respectively.

To constitute the spatial distribution map of rainfall, the Kriging method was adapted to interpolate the analyzed rainfall data points. This method is based on spatial autocorrelation data (Praveen et al., 2020). It uses the spatial correlation between marked data points to interpolate the corresponding values in the spatial distribution field (Praveen et al., 2020). In addition, the Kriging method allows for generating the estimation of the uncertainty surrounding each interpolated value point (Salehi et al., 2020). The Kriging method is commonly applied to conjecture the values $Z^*(x_0)$ at the point x_0 presented in Eq. 11.

$$Z^*(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \tag{11}$$

Where λ_i interests to weights and the conjecture of error variance $\sigma_k^2(x_0)$ is defined as Eq. 12.

$$\sigma_k^2(x_0) = \mu + \sum_{i=1}^{n} \lambda_i \gamma(x_0 - x_i) \tag{12}$$

In Eq. 12, μ is the Lagrange constant, $(x_0 - x_i)$ presents the semi-variogram value equivalent to the distance between x_0

and x_i. While γ consists of the regionalized variable theory and intrinsic hypotheses and it is presented by Eq. 13:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z(x_i)-Z(x_i+h)\right]^2 \qquad (13)$$

In Eq. 13, γ(h) presents semi-variance, h presents lag distance, Z presents the rainfall-related factors.

Accordingly, the Kriging method was applied to draw the maps of rainfall spatial distribution across the Plain of Reeds based on ArcGIS (Version 10.8) software.

Results and Discussion

The daily rainfall data series from 16 observation stations in the Plain of Reeds during the period 1984-2015 was transformed into annual rainfall before conducting the breakpoint detection and applying the SNHT and Pettitt tests. The results indicated that the obtained critical values (p) of 16 rainfall observation stations are larger than the significance level (α = 0.05), which implies that the rainfall data series at all observation stations are of quality and meet the requirements for further studies (Table 1).

The basic statistical features of annual rainfall (AR) across the study area, including minimum, maximum, standard deviation (SD), and coefficient of variation (CV), are presented in Table 2. Statistical analysis indicates that the annual mean rainfall (AMR) across the study area is approximately 1,513.9 mm, while the maximum AMR is recorded in the northeastern part, Tan Thanh, Moc Hoa, Ben Luc and Thu Thua (1,658.7, 1,637.1, 1,620.1 and 1,567.8 mm, respectively). The minimum AMR appears in the western and southwestern parts, Tan Hung (1,231.6 mm), Hong Ngu (1,287.6 mm), Cay Lay (1,389.7 mm) and My Tho (1,396.6 mm) (Table 2).

The SD of annual rainfall varies from 217.4 to 330.6 mm with the highest SD detected in the northeastern part i.e., Moc Hoa (330.6 mm), followed by Tan Thanh (329.7 mm) and Thu Thua (308.6 mm). While the lowest SD was concentrated in the southern part, i.e., Chau Thanh (217.4 mm), followed by Cai Lay (241.5 mm) and Cai Be (234.8 mm) (Table 2). It means that the study area has a strong fluctuation in AR.

Table 1. Results of breakpoint detection for rainfall data series at all observation stations across the study area during the period 1984-2015

No.	Station	Pettitt		SNHT	
		K_N	p-value	T_o	p-value
1	Hong Ngu	85	0.504	1.597	0.508
2	Cao Lanh	115	0.931	3.217	0.516
3	My Tho	122	0.674	3.416	0.562
4	Thap Muoi	109	0.698	1.657	0.638
5	Tam Nong	98	0.561	1.642	0.794
6	Tan Hung	103	0.617	1.590	0.834
7	Ben Luc	142	0.314	6.078	0.069
8	Moc Hoa	137	0.243	6.943	0.076
9	Thu Thua	141	0.318	6.172	0.081
10	Tan Thanh	139	0.279	6.534	0.079
11	Cai Be	136	0.235	4.716	0.209
12	Cai Lay	143	0.271	0.305	0.214
13	Tan Phuoc	138	0.197	6.187	0.061
14	Vinh Hung	123	0.215	5.314	0.057
15	Tan Hong	131	0.193	5.109	0.074
16	Chau Thanh	124	0.167	4.914	0.051

SNHT - Standard Normal Homogeneity test; Pettitt - Pettitt test; K_N - The test statistic; p - The critical values; T_o - The critical value of the test statistic

The spatial distribution maps of the CV of the AR and seasonal rainfall across the study area were established by applying the Kriging interpolation technique (Figure 3). The results pointed out that the southern part (Cai Be and Cay Lay stations) recorded the highest fluctuations of AR (e.g., 57.9 and 59.8%) while the southwest part (Cao Lanh station) recorded the lowest fluctuations of AR (51.9%) (Figure 3A). For RSR, the highest fluctuations were detected in the northeastern part, measuring 56.7% (Moc Hoa station), while the lowest fluctuations were recorded in the southern part (Cai Lay station), estimated at approximately 37.3% (Figure 3B). For DSR, the whole study area recorded a strong fluctuation in the CV, varying from 87.3 to 94.2% (Figure 3C). In general, a strong fluctuation in seasonal rainfall can lead to negative impacts on local agriculture activities, especially irrigation. For example, in rice cultivation paddies, rainfed agriculture plays an important role in irrigation in the dry season. The results of the Mann_Kendall test and Sen's slope estimator for

Table 2. Features of annual rainfall at the observation stations in the period 1984-2015

No.	Station	Min. AMR	Max. AMR	AMR	SD	CV
		(mm)				(%)
1	Hong Ngu	741.5	1854.0	1287.6	302.4	55.3
2	Cao Lanh	996.0	2387.8	1473.4	274.4	51.9
3	My Tho	1050.1	2050.3	1396.6	265.7	48.8
4	Thap Muoi	1051.3	1896.3	1343.9	251.9	46.4
5	Tam Nong	1040.4	1962.8	1489.5	274.3	54.7
6	Tan Hung	1000.6	1566.4	1231.6	297.3	52.6
7	Ben Luc	1055.5	2060.3	1620.1	298.7	48.7
8	Moc Hoa	998.8	2420.9	1637.1	330.6	56.7
9	Thu Thua	1367.5	3010.9	1567.8	308.6	54.6
10	Tan Thanh	1037.4	2223.5	1658.7	329.7	53.3
11	Cai Be	757.7	1884.2	1458.6	234.8	57.9
12	Cai Lay	932.5	1769.4	1389.7	241.5	59.8
13	Tan Phuoc	943.2	1973.5	1378.6	246.8	50.8
14	Vinh Hung	858.3	1857.1	1437.8	258.1	52.7
15	Tan Hong	794.7	1916.7	1407.3	243.8	54.9
16	Chau Thanh	874.9	1819.8	1437.8	217.4	56.4

Min. AMR - Minimum annual mean rainfall; Max. AMR- Maximum annual mean rainfall; AMR- Annual mean rainfall; SD - Standard deviation; CV - Coefficient of variation

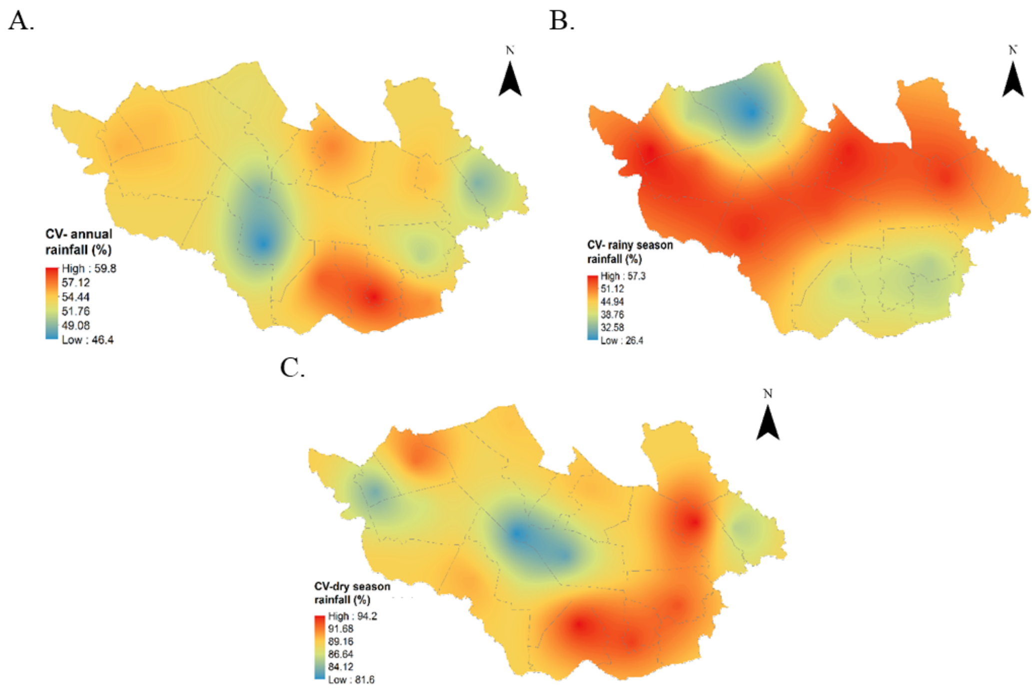

Figure 3. The distribution of the coefficient of variation (CV) of annual rainfall-AR (A), rainy season rainfall-RSR (B), and dry season rainfall-DSR (C) across the Plain of Reeds

rainfall features across the study area during the period 1984-2015 are presented in Table 3. A value of α=0.05 was applied to the analysis for Zs-statistics of the Mann_Kendall test and β- statistics of Sen's slope estimator.

For AR, the Zs showed positive values varying from 0.37 to 1.83, which were detected in 14 observation stations (Figure 4A). It implies an uptrend of AR over most of the study area, while only 2 out of 16 observation stations (e.g., Hong Ngu and Moc Hoa) were detected with Zs values from -0.6 to -0.04 (Table 3). For the RSR, the Zs values varied from 0.21 to 1.37 at 6 out of the 16 observation stations. This indicates that a slight increasing trend in RSR was recorded in less than 40% of the total area of the study (Figure 4B). A decreasing trend in the Zs value, varying from -1.87 to -0.17 was recorded at 10 out of 16 observation stations for DSR (Figure 4C). A study on the spatiotemporal variations in drought events over the Mekong Delta of Vietnam by Lee & Dang (2019) stated that a decreasing trend in the RSR was detected in the eastern and northeastern parts of the Mekong Delta. A similar result of Nguyen et al. (2022) reported that a decreasing trend in the RSR is contributed to an increasing trend in the six-month drought timescales.

In general, no observation stations for AR and RSR recorded significantly increasing or/decreasing trends. However, an increasing trend in DSR was detected at all observation stations, with a slight increase in trend (Zs value varying from 0.21 to 1.87) at 10 out of 16 observation stations, while a significant trend (Zs = 1.95÷2.97) was observed at 6 out of 16 observation stations (Table 3).

A study on the spatiotemporal variation trends in rainfall and drought over the Mekong Delta of Vietnam by Lee & Dang (2019) reported that an increasing trend in the DSR has occurred during the period 1984-2019. Accordingly, an increasing trend in DSR will bring a positive contribution

Table 3. Results of Mann_Kendall (Z_s) test and Sen' estimator slope (β) for rainfall features across the study area during the period 1984-2015

No.	Station	Annual rainfall - AR			Rainy seasonal rainfall - RSR			Dry seasonal rainfall - DSR		
		Z_S	p-value	β	Z_S	p-value	β	Z_S	p-value	β
1	Hong Ngu	-0.04	0.50	-0.03	0.21	0.46	-0.04	0.97	0.07	0.16
2	Cao Lanh	0.41	0.69	1.81	-0.21	-0.84	-0.78	1.64	0.06	0.12
3	My Tho	0.87	0.19	0.04	-0.87	0.95	-0.07	1.15	0.08	0.15
4	Thap Muoi	0.75	0.21	0.08	0.24	0.37	-0.06	0.23	0.37	0.19
5	Tam Nong	0.43	0.19	0.09	-0.39	0.67	-0.05	0.21	0.43	-0.02
6	Tan Hung	0.37	0.16	0.06	-0.17	0.38	-0.14	1.32	0.09	0.05
7	Ben Luc	0.42	0.35	-0.06	-0.62	0.29	-0.08	1.84	0.16	0.06
8	Moc Hoa	-0.60	0.55	-5.38	-1.35	0.18	-7.39	2.15	0.17	0.05
9	Thu Thua	0.58	0.43	-0.14	-1.46	0.24	-5.14	2.34	0.03	0.07
10	Tan Thanh	0.49	0.17	-1.12	-1.87	0.31	-3.76	1.95	0.05	0.09
11	Cai Be	1.18	0.24	5.49	0.86	0.39	3.13	2.97	0.02	0.17
12	Cai Lay	1.67	0.37	4.87	1.29	0.47	2.41	2.56	0.37	0.29
13	Tan Phuoc	1.59	0.61	3.94	1.16	0.51	2.76	2.21	0.42	0.38
14	Vinh Hung	1.83	0.42	4.15	-1.28	0.19	-6.21	1.87	0.13	0.08
15	Tan Hong	1.09	0.67	3.84	-0.98	0.21	-3.47	1.15	0.06	0.31
16	Chau Thanh	1.68	0.49	2.97	1.37	0.68	3.10	1.83	0.24	0.64

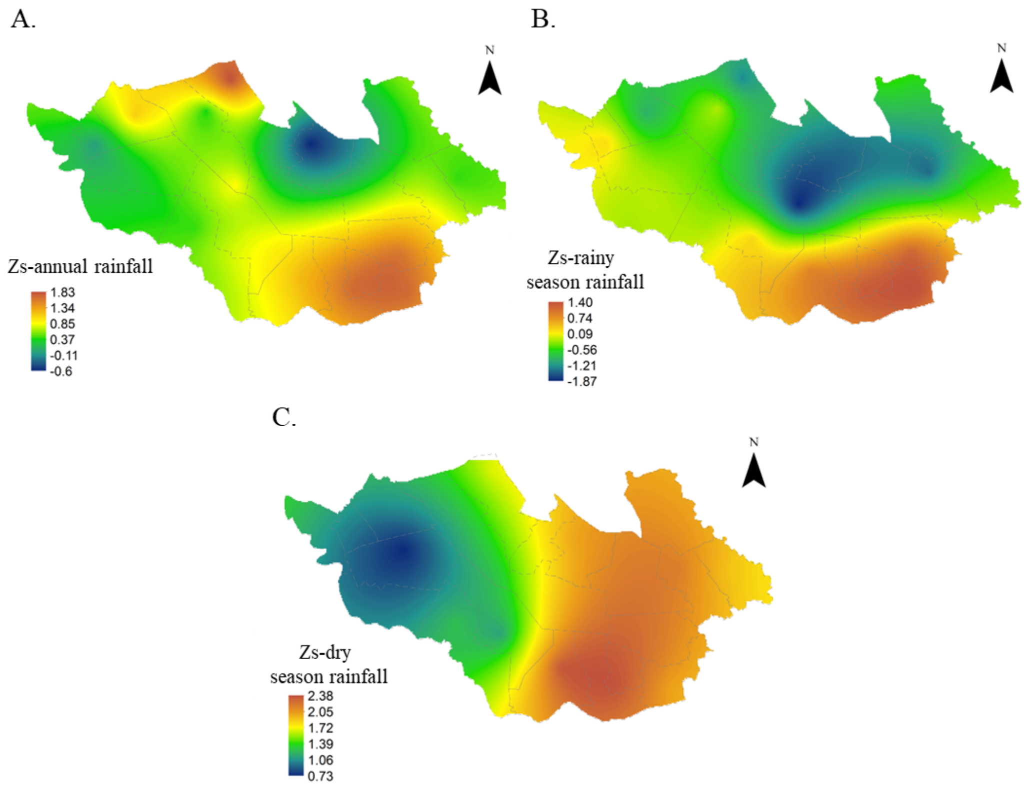

Figure 4. Spatial variation of rainfall features analyzed using the Mann_Kendall (Z_s) test for annual rainfall - AR (A), rainy season rainfall - RSR (B), and dry season rainfall - DSR (C) across the study area during the period 1984-2015

to agricultural activities such as supplementing the scarce irrigation water from irrigation canals. A decreasing trend in RSR will contribute to reducing the damage caused by heavy rainfall events to sowing activities, as well as the crop harvest.

Conclusions

1. No insignificant trends in increasing or decreasing annual and rainy seasonal rainfall were observed. However, an increasing trend was detected in dry season rainfall.
2. In the eastern part of the Plain of Reeds (including Moc Hoa, Thu Thua, Tan Thanh, Cai Be, Cai Lay and Tan Phuoc stations), there apears to be a significant increasing trend in dry season rainfall.
3. The findings indicated that the Plain of Reeds is experiencing a period of increased dry season rainfall, and it may contribute positively to agricultural production activities.

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